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STAINLESS STEELS' RESISTANCE TO HYDROEROSION,(U)
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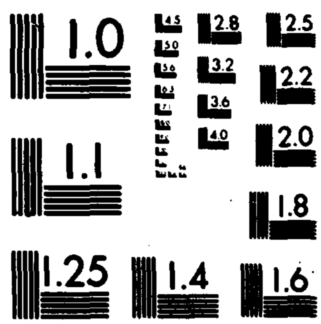

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FOREIGN TECHNOLOGY DIVISION

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by

V. M. OMel'chenko, S. L. Milichenko, A. G. Aleksandrov

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О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

STAINLESS STEELS' RESISTANCE TO HYDROEROSION

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Thanks to a high corrosion resistance stainless steels have found a wide application for the manufacture of hydraulic turbine parts.

Particularly type 20Kh13NL stainless chromium steels and 1Kh18N9T nickel-chromium steel [2, 3] were recommended and found use. Under conditions of weak cavitation effects these steels proved to be substantially more effective than the carbon steels commonly being used. However, the working experience of former years showed that with substantial intensity of the cavitation effect 1Kh18N9T and 20Kh13NL steels fail quickly [2, 4]. Therefore the question of developing and using materials which assure the turbines' durability has great significance.

The resistance to hydroerosion of several of the most common types of stainless steels which have roughly the same corrosion resistance was investigated in this work. The chemical composition and mechanical properties of these steels are presented in tables 1 and 2.

The samples for the tests were cut from a rolled section of industrial melts prepared in the works of the Dneprospetsstal' plant.

The conditions of the heat treatment and mechanical properties of the steels correspond to accepted norms, TU's [technical specifications] and GOST's [All-Union State Standards].

Table 1.

Сталь (2)	(1) Химический состав					
	C	Mn	Si	Cr	Ni	(3) Прочие элементы
0Х13	0,06	0.28	0.32	12.50	0.14	—
1Х13	0,11	0.32	0.38	13.91	0.20	—
2Х13	0.23	0,34	0.39	12.50	0.15	—
ЭИ736	0.13	0.55	0,41	11.8	—	1,75 W; 0,81 Mo; 0.22 V;
ЭИ961	0,12	0.41	0.23	10.93	1.80	1.88 W; 0.41 Mo; 0,24 V;
ЭП410	0,08	0,88	0.63	13.9	5.5	1,9 Cu;
1Х17Н2	0.13	0.42	0.34	17.0	1.86	—
ЭИ811	0,09	[illegible]	0.33	20.9	5,41	0.39 Ti;
ЭИ654	—	—	—	—	—	—
1Х18Н10Т	0.09	1.36	0.32	17.8	10.2	0.57 Ti;
ЭИ448	0.09	1.23	0.54	17.4	12.54	1.85 Mo; 0.36 Ti;
[illegible]	[illegible]	0.23	0.31	14.53	2.7	0.43 Mo

KEY: (1) The chemical composition; (2) The steel; (3) Remaining elements.

The tests of the samples were conducted on an impact-erosion test stand. The following were conditions of the test: the sample's impact speed with the jet of water was 78 m/s, the jet's diameter was 8 mm, the water's pressure head was 2.8 m, the width of the sample's working part was 10 mm. The resistance to erosion was estimated from the loss of the samples' weight in the course of each hour. The tests' total duration was six hours. Type 20Kh13NL steel used widely in hydraulic turbine construction as a cavitation resistant material was accepted as the standard. The standard samples were prepared from the material of a standard hydraulic turbine blade of the Kakhovskaya GES [hydroelectric power plant]. The relative resistance to erosion was determined as the ratio of the loss of weight of the samples of standard steel 20Kh13NL to the loss of weight of samples of the investigated material during the period of testing.

Metallographic and X-ray diffraction examinations as well as measurements of hardness and microhardness of the samples in the zone of erosion were conducted periodically in order to study the

changes which take place on the surface layers of the metal during the first hour of the tests. The X-ray analysis was conducted on a URS [universal speed regulator]-50IM [testing machine] unit under cobalt irradiation.

As a result of the tests it was established that OKh13 steel having a ferrite structure with a small amount of tempered martensite has the least resistance to erosion of the stainless chromium steels. The metallographic examinations of the samples' surface showed that the failure is first localized in the ferrite phase and occurs by means of plastic deformation and the development of fatigue microcracks both inside the grains as well as along their boundaries.

The samples of OKh13 steel are characterized by an insignificant strengthening and the absence of phase transformations during the process of repeated microshock loading. The resistance of this steel is lower than the standard 20Kh13NL steel (Table 2).

Increasing the carbon content in the chromium steels causes a noticeable increase of the resistance to erosion which is explained by the lowering of structural heterogenity due to the elimination of structurally free ferrite and the increase of strength properties of the steels. It is characteristic that with the same carbon content the resistance of rolled steel 2Kh13 is more than double the resistance of cast steel 20Kh13NL. As is known, the bulky casting of 20Kh13NL steel is characterized by a large structural heterogeneity and instability of the mechanical properties which were not eliminated by repeated heat treatment [4].

The alloying of chromium steels with tungsten, molybdenum, and vanadium (for example, the EI756 type steel) contributes to the increase of their strength properties and as a result to the resistance to erosion. However, in EI756 steel ferrite which is not hardened by precipitation hardening is present and develops concentrations of stresses, while failing quickly. Therefore, the resistance of this steel insignificantly exceeds the resistance of the standard. The additional alloying of this steel with nickel of up to 2-2.5% sharply increases the resistance to erosion as occurs

Table 2.

Сталь (1)	Термическая обработка (2)	Механические свойства (3) σ_s, МН/м² (4)	$\sigma_в$, МН/м² (4)	δ, %	$a_н$, МН·м/м² (5)	НВ	(6)	(7)
0Х13	Закалка 1050° С 40 мин, масло (8) Отпуск 760° С 30 мин, масло (9)	435,0	640,0	26	1,75	2070	920	0,6
1Х13	Закалка 1050° С 40 мин, масло (8) Отпуск 740° С 40 мин, масло (10)	530,0	720,0	21,5	1,75	2070	500	1,1
2Х13	Закалка 1050° С 40 мин, масло (8) Отпуск 770° С 2 ч, воздух (11)	710,0	910,0	17,8	0,7	2290	233	2,4
ЭИ736	Закалка 1050° С 40 мин, масло (8) Отпуск 780° С, 1 ч масло (12)	610,0	805,0	20,0	1,02	2290	433	1,2
ЭИ961	Закалка 1020° С 40 мин, воздух (13) Отпуск 700° С, 2 ч, воздух (14)	1100,0	1255,0	18	1,03	3520	62	9,2
ЭП410	Закалка 950° С, 1 ч воздух (15) Отпуск 650° С (16)	1000,0	1310,0	16	1,08	3110	184	3,0
1Х17Н2	Нормализация 950° С (17) Старение 450° С 1 ч, воздух (18) Закалка 1020° С, 40 мин, масло (19) Отпуск 375° С, 1 ч, воздух (20)	1080,0	1320,0	14	1,02	3320	135	4,2
ЭИ811	Закалка 1000° С, 40 мин, вода (21) Отпуск 550° С, 1 ч охлаждение до 300° С с печью (22)	440,0	765,0	23,0	1,75	2350	230	2,5
ЭИ654	Закалка 950° С 40 мин, вода (23)	420	770	51,5	1,4	2020	131	4,3
1Х18Н10Т	Закалка 1050° С 40 мин, вода (24)	245	550	59	—	1960	720	0,8
ЭИ448	Закалка 1050° С 40 мин, вода (24)	230	530	55,5	—	2730	346	1,6
ДИ1	Закалка 980° С 40 мин, масло (25) Отпуск 640° С, 1 ч, воздух (26)	—	1085,0	15,5	0,73	2860	140	4,0

KEY: (1) Steel; (2) Heat treatment; (3) Mechanical properties; (4) MN/m^2; (5) MN·m/m^2; (6) Loss of weight after 6 h of tests, in mg; (7) Relative resistance to erosion; (8) Quenching at 1050°C for 40 min. in oil; (9) Tempering at 760°C for 30 min. in oil; (10) Tempering at 740°C for 40 min. in oil; (11) Tempering at 770°C for 2 h in air; (12) Tempering at 780°C for 1 h in oil; (13) Quenching at 1020°C for 40 min in air; (14) Tempering at 700°C for 2 h in air; (15) Quenching at 950°C for 1 h in air; (16) Tempering at 650°C; (17) Normalization at 950°C; (18) Aging at 450°C for 1 h in air; (19) Quenching at 1020°C for 40 min in oil; (20) Tempering at 375°C for 1 h in air; (21) Quenching at 1000°C for 40 min in water; (22) Tempering at 550°C for 1 h then cooling to 300°C with a furnace; (23) Quenching at 950°C for 40 min in water; (24) Quenching at 1050°C for 40 min in water; (25) Quenching at 980°C for 40 min in oil; (26) Tempering at 640°C for 1 h in air.[4]

in type EI961 steels. The introduction of nickel eliminates the ferrite component and contributes to the obtainment of a homogeneous martensitic structure after quenching and of a sorbitic structure with additional hardening after tempering as a result of separating the finely divided carbides and the intermetallic compound phases (Fe_2W, Fe_2Mo) which contributes to the increase of the steel's strength properties. The high strength properties, the lack of a heterogeneous structure in conjunction with a high strengthening with microplastic deformations assures steel EI961 the highest resistance to erosion, which several times exceeds the resistance of standard 20Kh13NL steel.

The resistance to erosion of 1Kh17N2 and DI1 steels may serve as confirmation to the aforementioned. These steels are similar in mechanical properties. However 1Kh17N2 steel in the initial state has a martensitic structure with a small amount (up to 10%) of ferrite and residual austenite. DI1 steel is developed as an alternative to 1Kh17N2 steel and is characterized by the lack of a ferritic phase. In the initial state DI1 steel has a homogeneous structure of a tempered sorbite strengthened by separating the precipitation particles. This steel's resistance to erosion is not inferior to 1Kh17N2 martensitic steel's resistance and exceeds the resistance of the standard steel by several times.

Thus the homogeneous structure of strengthened sorbite is not inferior in resistance to martensite which is considered to be the most resistant structure against erosion action [3, 4].

Of the nickel-chromium steels austenitic steel 1Kh18N10T has the least resistance to erosion. In the initial state this steel has a structure of stable austenite with isolated inclusions of carbides and is characterized by low strengthening in the process of cyclic deformation and by the quick formation and development of areas of failure along the slip lines and along the grain boundaries. The resistance to erosion of 1Kh18N10T steel is 20% lower than that of the standard steel.

The additional introduction of 2% molydenum (steel E1448) almost doubles the resistance to erosion in comparison with 1Kh18N10T steel. A still larger effect is observed when alloying the austenite of a nickel-chromium steel with silicon. EI654 steel has an austenitic structure with a small amount (5-10%) of δ-ferrite. Ferrite's low resistance to erosion failure with such small amounts is compensated by the positive influence of silicon on the austenite's strengthening. The presence of ferrite as well as a lowering of the energy of packing defects in EI654 steel caused by introducing silicon results in a strong hardening of the austenite both by cold deformation [1] and by the repeated deformation of microvolumes with the cavitation effect. Moreover, austenite steel EI654 is unstable and undergoes a martensite transformation with erosion failure. This additionally hardens the metal of the surface layers of EI654 steel's samples.

The EI811 austenite-ferritic steel ($\alpha:\gamma$ = 1:1) has a comparatively low resistance to erosion. The failure starts from the α-phase and along the phase interfaces and expands into the γ-phase. Although the steel contains up to 50% of the α-phase the presence of unstable austenite contributes to the increase of its resistance to erosion by more than double in comparison with the standard steel.

EP410 steel has a high resistance to erosion. This steel belongs to a class of age-hardening steels. In the as received condition (quenching at 980°C, tempering at 640°C, normalization at 950°C and aging at 450°C) the steel contains about 5-8% residual austenite and martensite, strengthened bvy the separation of intermetallic compound phases. In such a structural state the steel is characterized by high strength properties and is well resistant to failure by microshock stresses. The failure of this steel, just as EI961 steel, begins after a prolonged incubation period (2-3 hours) and the process of failure itself, occurs more uniformily with less selectivity in comparison with other tested steels.

Based on what has been said the following conclusions may be drawn:

1. Stainless steels' resistance to hydroerosion is determined to a considerable extent by the structural state.

2. The steels with a homogeneous martensitic and sorbite structure strengthened by aging and also steels with a structure of unstable austenite intensively hardened by microshock stress with a formation of deformed martensite have the highest resistance to erosion.

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